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(54) LAMINATIONS FOR ELECTROMAGNETIC DEVICES

(71) I, HARRY HIRST, a British subject of, The Spinney, Nore March Road, Wootton Bassett, Wiltshire, England, do hereby declare the invention, for which I pray that a patent may be granted to me, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to laminations for the magnetic cores of electromagnetic devices and to methods of making such laminations. For illustrative purposes, the invention will be described in relation to transformers however it is to be understood that the laminations according to the invention may be used for other electromagnetic devices, such as saturable reactors, inductors or chokes.

At the present time it is conventional to make the magnetic core of an electromagnetic device such as a transformer of a stack of laminations on which a coil is wound. It is highly desirable that the cost of producing laminations for such electromagnetic devices should be kept to a minimum and as a result it has been the practice to stamp out the laminations from sheet material in such a way as to minimise the waste of sheet material. One form of laminations which can be stamped out from sheet material in this way comprises an E-shaped member with an I-shaped member arranged transverse to the three parallel limbs and having one of its edges in contact with the end edges of the three parallel limbs. To prepare such laminations without waste, the I-shaped members consist of the metal which is removed from the sheet to provide the spaces between the three parallel limbs of the E-shaped member.

Laminations made in this way are known as "no-waste" laminations.

Using conventional "no-waste" laminations of a given size, it is possible to make a range of differently rated electromagnetic devices. However, the range is relatively narrow and consequently the conventional "no-waste" laminations are made in a large number of different sizes so that a wide range of differently rated electromagnetic devices may be made. As a consequence, if a transformer manufacturer wishes to be able to produce electromagnetic devices whose ratings vary over a wide range, he must stock or manufacture, this large number of different sizes of laminations.

For the sake of economy, it is desirable to reduce the number of different sizes of laminations required to produce the wide range of different ratings of electromagnetic devices, and the present invention aims, at least in preferred embodiments, to go at least some way towards meeting this.

In one aspect the present invention provides an E-shaped member for use as a lamination in the core of an electromagnetic device, in which, if the width of the centre of the three parallel limbs is x, the spacing between said centre limb and each of the outer limbs of said three is x, the width of each of said outer limbs and of the limb transverse thereto is $\frac{1}{2}x$, the length of said transverse limb is $4x$, the length of the centre limb of a first of said outer limbs is $3x$, and the length of the second outer limb is $3\frac{1}{2}x$ so that the free end portion thereof projects a distance $\frac{1}{2}x$ beyond the free ends of the centre and first outer limbs, the length of the three parallel limbs being measured from the inner edge of the transverse limb, and wherein x is within the range 14 mms to 64 mms.

Preferably x has one of the following values:—

x equals 14 mms
x equals 19 mms
x equals 23 mms
x equals 28 mms
x equals 33 mms
x equals 44 mms
x equals 54 mms
x equals 64 mms

If laminations are produced in each of the above different sizes of x it has been found that a wide range of different rated electromagnetic devices can be produced.

In a second aspect the invention provides

a method of making a set comprising a plurality of laminations of different but related sizes comprising cutting E-shaped members, in each of which, if the width of the centre of the three parallel limbs is x, the spacing between said centre limb and each of the outer limbs of said three is x, the width of each of said outer limbs and of the limb transverse thereto is $\frac{1}{2}x$, the length of said transverse limb is $4x$, the length of the centre limb and a first of said outer limbs is $3x$, and the length of the second outer limb is $3\frac{1}{2}x$ so that the free end portion thereof projects a distance $\frac{1}{2}x$ beyond the free ends of the centre and first outer limbs, the length of the three parallel limbs being measured from the inner edge of the transverse limb, and cutting I-shaped members from sheet material; each I-shaped member having a length of $3\frac{1}{2}x$ and a width of $\frac{1}{2}x$; wherein the different sizes of the plurality of laminations are related such that if, in a first size of lamination, the dimension x is equal to y units, then the dimension x in other sizes of lamination are as follows: $19y/14$; $23y/14$; $28y/14$; $33y/14$; $44y/14$; $54y/14$; and $64y/14$ units.

It has been discovered that if laminations are produced by the above method, in the relative sizes specified, a wide range of electromagnetic devices may be produced from the resulting laminations.

The laminations according to the invention, or made according to the method of the invention, are suitable for use with aluminium coils, in connection with which reference should be made to co-pending application No. 8056/74 (Serial No. 1,466,879), from which the present application is divided. Further description of the present invention will assume that the laminations are to be used with aluminium coils, and such further description is by way of example with reference to the accompanying drawings, in which:—

Figure 1 is a plan view of a lamination according to a preferred embodiment of the present invention;

Figure 2 is a plan view of a piece of sheet metal illustrating how two laminations illustrated in Figure 1 can be cut therefrom substantially without waste;

Figure 3 is a perspective view of an electric coil wound on a bobbin, for use in the transformer in which the laminations are to be used;

Figure 4 is a cross-section of the coil shown in Figure 3 and illustrates a step in the assembly of the transformer;

Figure 5 is a section similar to Figure 4 but showing a more advanced stage of assembly of the transformer;

Figure 6 is a view similar to Figure 1 but showing a conventional lamination;

Figure 7 illustrates how the lamination of Figure 6 can be made from sheet metal substantially without waste;

Figure 8 is a diagram showing a choke according to an embodiment of the invention;

Figure 9 is a diagram showing a saturable reactor according to an embodiment of the invention; and

Figure 10 is a diagram showing an alternative form of saturable reactor embodying the invention.

Referring to Figure 1 of the accompanying drawings, the lamination shown comprises an E-shaped member 2 having three parallel limbs 4, 6, 8 with spacings 10 and 12 between them, a limb 14 transverse to the parallel limbs 4, 6, 8 and integral therewith, and an I-shaped member 16. Bolt holes 18 are provided in the members 2 and 16.

If, as shown in Figure 1, the width of the centre limb 6 of the three parallel limbs 4, 6, 8 of the member 2 is x, the relative dimensions of the limbs and spaces of the lamination shown in Figure 1 are as follows:

Limb/Space	Width	Length
Limb 4	$\frac{1}{2}x$	$3x$
Limb 6	x	$3x$
Limb 8	$\frac{1}{2}x$	$3\frac{1}{2}x$
Space 10	x	$3x$
Space 12	x	$3x$
Limb 14	$\frac{1}{2}x$	$4x$
Member 16	$\frac{1}{2}x$	$3\frac{1}{2}x$

It will also be recognised that the distance from the left-most end of the limb 8 to the right hand edge of the limb 14 is $4x$, so that the outline of the lamination 2 is a square. Since the limb 14 is at right angles to the limbs 4, 6, 8, the limb 8 has an end portion 8′ projecting a distance $\frac{1}{2}x$ beyond the ends of the limbs 4, 6.

The lamination illustrated in Figure 1 can, if two such laminations are made, be cut from a rectangular piece of sheet metal measuring $4x$ by $5x$ without waste, if the cut lines are arranged as shown in Figure 2. Figure 2 is marked with the same reference numbers as Figure 1 but with the suffix *a* to indicate the parts of one of the laminations and the suffix *b* to indicate the parts of the other lamination. Also, the I-members 16*a*, 16*b* are shaded to distinguish them more clearly from the two E-members.

Preferably, the cutting out of the laminations is effected by a stamping operation. If desired, more than two of the laminations can be stamped out from a single sheet simultaneously. This can be achieved without waste, if the sheet is divisible into rectangles measuring $4x$ by $5x$.

The laminations may be made of conventional transformer iron and the opposite faces will be provided with an insulating coating such as by varnishing or oxidising.

To make the transformer, the laminations are assembled into a stack, together with coils of aluminium wire. As shown in Figures 3 to 5, the coils are first wound onto a bobbin 20 which comprises a rectangular tube 22 which is dimensioned to fit neatly over the centre limbs 6 of the E-shaped laminations 2 and a rectangular outwardly directed flange 24 at each end. A primary coil 26 of aluminium wire is first wound onto the tubular portion 22 of the bobbin 20. Then a layer of insulation 28 is wrapped around the primary coil 26 and thereafter a secondary coil 30 is wound on top of the insulation 28. The operations of winding the coils onto the bobbin 20 may be carried out in a conventional manner. The material from which the bobbin 20 is made is preferably also a conventional electrically insulating material used for this purpose, for example a synthetic plastics material.

As shown in Figures 4 and 5, the laminations are assembled with the coil by firstly inserting the centre limbs 6 of the E-shaped laminations into the rectangular tubular portion 22 of the bobbin 20. The flanges 24 are formed to be a neat fit within the spaces 10, 12 of the E-shaped members 2 and thus, as shown in Figure 4, the projecting end portions 8′ of the limbs 8 of the E-shaped members 2 may be used in co-operation with the edges of the flanges 24 as guides for correctly positioning the E-shaped members 2 and the bobbin 20 relative to each other during the assembly.

After the E-shaped members have been inserted, the I-members 16 are put in position as shown in Figure 5 with one longitudinal edge 16′ in contact, or at least in close proximity, with the end edges 4′ and 6′ of the limbs 4 and 6 of the E-member 2 and with one end edge 16″ in contact, or at least in close proximity, with the inner longitudinal edge 8″ of the limb 8 at the projecting end portion 8′ thereof. The laminations may then be secured in position, in the usual way, as by inserting bolts through the bolt holes 18. As is conventional, contact between the edges of the member 16 and the member 2 should be as firm and as close as possible to minimise the magnetic reluctance introduced into the core by any gaps at these points. It is also preferred, as illustrated in Figure, that some of the E-shaped member 2 should be inserted into the tube 22 from the right as shown in that Figure and some from the left. If the lamination has insulation on only one side, the successive laminations inserted should be arranged so that in the assembled core the longer limb is alternately above and below the wound bobbin (as seen in Figure 4) to ensure that the insulated side of the lamination will always be on the same side thus ensuring that each lamination is insulated from its neighbours. Should the laminations be insulated both sides, then the longer limb of all laminations in the assembled core may be either above or below the bobbin if required. The two methods of assembly should not be mixed. In a preferred embodiment, three E-shaped members 2 will first be inserted from, say, the right and then three from the left and then another three from the right etc. until the stack has been built up to the required depth. As a result of this, the "gaps" in the magnetic path arising at the points of contact between the edges of the members 16 and the co-operating members 2 will be distributed evenly between the left hand side and the right hand side of the transformer as seen in Figures 4 and 5 thus, the magnetic reluctance of the stack as considered as a whole will be balanced as regards the left and right hand sides of the transformer.

Aluminium wire is commercially available and such may be used for the coils 26 and 30. Such wire may be insulated by any conventional insulating material, for example a synthetic enamel, for example polyvinyl acetal.

The resistivity of aluminium is greater than that of copper. As a result, for an aluminium wire to have the same resistance per unit length as copper wire of a given cross-sectional area, the cross-sectional area of the aluminium wire would have to be 1.6 times the cross-sectional area of the copper wire. Thus, a coil, such as the coils 26 and 28, when made of aluminium wire and having a given number of turns will take up more space than a coil of copper wire of the same resistance per unit length and having the same number of turns. It has been found that the size of the windows provided by the spaces 10 and 12 in the laminations described with reference to Figures 1 to 5, in relation to the dimensions of the limbs of the laminations, is appropriate for accommodating electrical coils of aluminium wire.

The economic production of transformers which will operate satisfactorily requires that the sizes of the limbs of the core, the windows of the core and the coils have to be properly interrelated. This will be better understood by consideration of the following numerical examples, which will also demonstrate the advantages which can be achieved by utilising the present invention. In the following examples, a mixture of metric units with FPS units is employed as at the present time such a mixture is conventional in the transformer industry.

Example 1a

A typical conventional transformer will be described, employing the conventional no waste lamination, and copper coils.

The lamination is shown in Figure 6. It

comprises an E-shaped member 50 having three limbs 52, 54 and 56 which are parallel to one another and of equal length, and a limb 58 transverse thereto. The lamination also includes an I-shaped member 60 arranged parallel to the limb 58 and having one longitudinal edge 60′ in contact with the end edges of the three limbs 52, 54 and 56.

The reference number 62 indicates the spaces between the limbs 52, 54 and 56, which spaces constitute the windows which accommodate the coil or coils of the finished transformer. As shown on the drawings, if x is the width of the centre limb 54, the various dimensions of the lamination are as follows:

Limb/Space	Width	Length
Limb 52	$\frac{1}{2}x$	$1\frac{1}{2}x$
Limb 54	x	$1\frac{1}{2}x$
Limb 56	$\frac{1}{2}x$	$1\frac{1}{2}x$
Limb 58	$\frac{1}{2}x$	$3x$
Space 62	$\frac{1}{2}x$	$1\frac{1}{2}x$
Member 60	$\frac{1}{2}x$	$3x$

Two such laminations can be stamped out simultaneously, with substantially no waste, from a sheet of metal measuring $3x$ by $4x$ as shown in Figure 7. Alternatively, a single lamination as shown in Figure 6 could be made from a sheet of metal measuring $3x$ by $2x$ as will be understood by considering the portion of Figure 7 to either the left of the right hand side of the dotted line 70. In this case, the metal removed to form the spaces 62 would be in two pieces which would have to be joined together as shown by the dotted line 74 in Figure 6, to form the member 60.

It is assumed that the primary and secondary coils are wound one on top of the other on a bobbin, for example as illustrated in Figures 3 and 4. The following illustrates numerically a typical transformer utilising the laminations of Figure 6:

Rating: 600 V/A (at 200 volts input and output)
Flux density: 15,000 lines/square cm
Dimension x: 1.75 inches
Depth of Stack: 2.75 inches
Weight of Iron in Core: 14 lbs.
Diameter of Copper Wire: 0.058 inches

Primary Coil:

Turns	205
Turns/Layer	40
Layers	6

Secondary Coil:

Turns	210
Turns per layer	40
Layers	6

Total Length of Wire: 144 yards (131 metres)
Total Weight of Copper in Coils: 4.41 lbs.
Total Weight of Copper and Iron in the transformer: 18.41 lbs.
Resulting regulation 2.5% at unity power factor

This arrangement of the coils will take up about 0.859 inches of the available 0.875 inches of window space (0.875 being the equivalent of

$$\frac{x}{2}$$

where x, as stated above, is 1.75 inches).

Example 1b

In this example, the transformer is made according to the invention.

Rating: 600 V/A (at 200 volts input and output)
Flux Density: 15,000 lines/square cm
Dimension x: 33 mms
Depth of Stack: 82.5 mms
Total weight of Iron in Core: 15.3 lbs.
Diameter of Aluminium Wire used for coils: 0.072 inches (or 1.8 mms)

Primary Coil:

Turns	232
Turns per layer	48
Layers	5

Secondary Coil:

Turns	240
Turns per layer	48
Layers	5

Total Length of Wire used: 165 yards (149 metres)
Total Weight of Aluminium in Coils: 2.331 lbs.
Total Weight of Aluminium and Iron in transformer: 17.631 lbs.
Regulation given 2.8% at unity power factor

It will be noted that the rating of 600 VA and flux density of 15,000 lines per square cm of this example are identical to Example 1a, and the regulation of 2.8% is still comparable with the regulation of 2.5% of Example 1a.

Although the regulation of 2.8% in Example 7b is slightly greater than the regulation of 2.5% of Example 1a, this is still well within acceptable limits.

It has been found that the range of different transformers that can be made with a single value of x in the conventional lamination of Figure 6 is much less than the range which can be made in accordance with the

invention with laminations as described with reference to Figures 1 to 5 with a single given value of x. It will be understood that the amount of iron in the core can be varied by varying the depth of the stack of laminations (i.e. the number of laminations in the stack). However, there is a practical limit in that, to avoid problems in winding the coils, the stack depth should not exceed $2\frac{1}{2}$ times the dimension x since if this ratio is exceeded, the coils become too rectangular (as seen from the end) for rapid and easy winding. In particular, if the stack depth of the core of Example 1a is varied, within the above mentioned limits, between 1.75 and 2.75 inches (wider variation than this to the extreme of the x to $2\frac{1}{2}x$ range is not practical because the window size is not large enough to take the appropriate number of turns of the coil required for the resulting KVA output) transformers rated at between 250 VA and 600 VA and flux density of 15,000 lines per square cm can be made with appropriate design of the coils. However, in Example 1b, varying the stack depth from x to $2\frac{1}{2}x$, i.e. between 33 mms and 82.5 mms, enables transformers rated at between 95 VA and 600 VA to be produced with appropriate designs of the coils.

In Example 1b, the aluminium coils will in fact only use up about 22 mms of the available 33 mms of window space. However, this is not material since this wasted window space represents very little in terms of extra iron as compared to the amount of iron used in the transformer of comparable specification of Example 1a. In any case, in view of the no-waste construction no iron is in fact wasted from the windows.

It will be seen that the space taken up by the aluminium coils of Example 1b is greater than the available window space of Example 1a and thus such coils could not be used with the laminations of Example 1a. As stated above, the aluminium coils require extra space because aluminium wire of given resistance has to be thicker than copper wire of the same resistance since aluminium has a greater resistivity than copper. It was also stated above that the cross-sectional area of aluminium wire must be 1.6 times greater than that of copper wire to obtain the same resistance. However, in Example 1b, a factor 1.4:1 has been used for the cross-sectional area of the aluminium wire compared to the copper wire of Example 1a (ii) because the specific heat of aluminium is greater than copper and therefore, even though the resulting higher resistance of the aluminium will produce more heat than if the cross-sectional area were based on a ratio of 1.6:1, the actual temperature rise provided by such heat will be less than would be produced in copper with an equivalent production of heat. Also the unused window space in Example 1b permits freer circulation of air around the coils so that the heat generated is more readily dissipated into the atmosphere.

It will be seen from the above that when a lamination as described with reference to Figure 1 is used, it may be produced by a no waste technique as described with reference to Figure 2 and aluminium, instead of copper, coils may be employed. Additional advantages are savings in weight; the lamination is a perfect square so that it can easily be mounted with the coils either horizontal or vertical since the end clamps and/or feet as usually employed can be attached at either side; assembly is easier than with the lamination of Figure 6 since the projecting portion 8′ of the limb 8 acts as a guide in co-operation with the edge of the flange 24 of the bobbin 20 and also owing to this projecting end piece acting as a "stop" which locates the I-members 16 in the correct position.

It has been explained above that the range of different transformers that can be made with the laminations according to the invention having the value of x given in Example 1(b), is greater than the range of transformers that can be made from the conventional lamination with the value of x given in Example 1(a). It has been discovered that a particularly wide range of transformers may be made from a relatively small number of different sizes of lamination in accordance with the invention. Preferably, eight sizes of lamination in accordance with the invention are produced.

It is preferred that the range of sizes should be such that x is within the limits 14 mms to 64 mms, and specifically it is preferred that the eight sizes be as follows:

Size No. 1	x=14 mms
Size No. 2	x=19 mms
Size No. 3	x=23 mms
Size No. 4	x=28 mms
Size No. 5	x=33 mms
Size No. 6	x=44 mms
Size No. 7	x=54 mms
Size No. 8	x=64 mms

Thus, the transformer manufacturer may easily stock this range of sizes to give flexibility in his transformer production.

Examples 1a and 1b have demonstrated the advantages of the transformer according to the invention when x equals 33 mms (Size No. 5), this size having been chosen for the main example as it is in the middle of the preferred range. The following examples, comparing transformers of similar rating made on the one hand in a conventional manner using copper wire and the laminations of Figure 6 and on the other hand made in accordance with the inven-

tion, will demonstrate that the remaining of the above listed eight sizes also provide the advantages mentioned and will show how this range of sizes provides a very wide total range of transformers, as compared to the total range which would be available with conventional transformers.

Example 2a—Conventional Transformer
Rating: 12.5 KVA (at 400 volts input and 400 volts output)
Flux Density: 9,000 lines per square cm
Dimension x: 4.5 inches
Depth of Stack: 6.5 inches
Weight of Iron in Core: 220 lbs.
Dimension of Copper Wire: 0.3 inches by 0.105 inches strip

Primary Coil:

Turns	112
Turns/Layer	20
Layers	6

Secondary Coil:

Turns	117
Turns per layer	20
Layers	6

Total length of Copper: 185 yards
Total Weight of Copper in Coils: 67.5 lbs.
Total Weight of Copper and Iron in the Transformer: 287.5 lbs.
Resulting regulation 4% approx. at U.P. factor

In this transformer, the coils will take up about 1.6 inches of the available 2.25 inches of window space.

With this value of x, the available variation in rating is 8.5 KVA to 12.5 KVA, achieved by varying the stack depth between 4.5 inches and 6.5 inches, and appropriate design of the coils. Flux density varies between 11,000 lines per square cm and 9,000 lines per square cm.

Example 2b—Transformer according to the Invention
Rating: 12.5 KVA (at 400 volts input and 400 volts output)
Flux Density: 12,300 lines per square cm
Dimension x: 64 mms
Depth of Stack: 160 mms
Total Weight of Iron in core: 111 lbs.
Cross-sectional dimensions of Aluminium used for Coils: 0.31 inches by 0.145 inches

Primary Coil:

Turns	149
Turns per layer	22
Layers	7

Secondary Coil:

Turns	158
Turns per layer	22
Layers	8

Total Length of aluminium used: Approx. 230 yards
Total Weight of Aluminium in Coils: 35.5 lbs.
Total Weight of Aluminium and Iron in transformer: 146.5 lbs.
Regulation given approx. 6%.

The coils will take up about 59.5 mms (2.35 inches) of the available 64 mms (2.52 inches) of window space.

With this value of x, the available variation in rating is 2 KVA to 12.5 KVA, achieved by varying the stack depth between 64 mms to 160 mms, and appropriate design of the coils. Flux density varies between 15,000 to 12,300 lines per square cm.

Example 3a—Conventional Transformer
Rating: 8 KVA (at 400 volts input and 400 volts output)
Flux Density: 11,500 lines per square cm
Dimension x: 3.5 inches
Depth of Stack: 6½ inches
Weight of Iron in Core: 133 lbs.
Cross-sectional dimensions of Copper: 0.2 by 0.1

Primary Coil:

Turns	114
Turns/Layer	23
Layers	5

Secondary Coil:

Turns	117
Turns per layer	23
Layers	6

Total Length of Copper: 167 yards
Total weight of copper in coils: 39 lbs.
Total Weight of Copper and Iron in the transformer: 172 lbs.
Resulting regulation about 2.4% at U.P. factor.

In this transformer, the coils will take up about 1.5 inches of the available 1.75 inches of window space.

With this value of x, the available variation in rating is 2.25 KVA to 8 KVA, achieved by varying the stack depth between 3.5 inches to 6.5 inches, and appropriate design of the coils. Flux density varies between 12.500 lines per square cm to 11,500 lines per square cm.

Example 3b—Transformer according to the Invention
Rating: 8 KVA (at 400 volts input and output)

Flux Density: 12,300 lines per square cm
Dimension x: 64 mms
Depth of Stack: 160 mms
Total Weight of Iron in Core: 111 lbs.
Cross-sectional dimensions of Aluminium used for coils: 0.31 inches by 0.095 inches

Primary Coil:

Turns	149
Turns per layer	22
Layers	7

Secondary Coil:

Turns	155
Turns per layer	22
Layers	7

Total Length of aluminium used: about 205 yards
Total Weight of Aluminium in Coils: 21 lbs.
Total Weight of Aluminium and Iron in transformer: 132 lbs.
Regulation given approx. 4% at U.P. factor

The coils will take up about 43 mms (1.7 inches) of the available 65 mms (2.52 inches) of window space.

With this value of x, the available variation in rating is 1.5 KVA to 8 KVA, achieved by varying the stack depth between 64 mms to 160 mms, and appropriate design of the coils. Flux density varies between 15,000 lines per square cm to 12,300 lines per square cm.

Example 4a—Convention Transformer
Rating: 4.25 KVA (at 400 volts input and 400 volts output)
Flux Density: 12,000 lines per square cm
Dimension x: 3 inches
Depth of Stack: 5.5 inches
Weight of Iron in Core: 82.5 lbs.
Diameter of Copper Wire: 0.116 inches (or 3 mms)

Primary Coil:

Turns	149
Turns/Layer	34
Layers	5

Secondary Coil:

Turns	156
Turns per layer	34
Layers	5

Total Length of Wire: 195 yards or 177 metres
Total Weight of Copper in Coils: 24 lbs.
Total Weight of Copper and Iron in the transformer: 106.5 lbs.
Resulting regulation approx. 2.6% at U.P. factor

In this transformer, the coils will take up about 1.4 inches of the available 1.5 inches of window space.

With this value of x, the available variation in rating is 1.5 KVA to 4.25 KVA, achieved by varying the stack depth between 3 inches to 5.5 inches, and appropriate design of the coils. Flux density varies between 13,500 to 12,000 lines per square cm.

Example 4b—Transformer according to the Invention
Rating: 4.25 KVA (at 400 volts input and output)
Flux Density: 12,300 lines per square cm
Dimension x: 54 mms
Depth of Stack: 135 mms
Total Weight of Iron in core: 66.5 lbs.
Cross-sectional dimensions of Aluminium used for coils: 0.21 inches by 0.07 inches

Primary Coil:

Turns	207
Turns per layer	28
Layers	8

Secondary Coil:

Turns	215
Turns per layer	28
Layers	8

Total Length of Aluminium used: 246 yards or 224 metres
Total Weight of Aluminium in coils: 12.75 lbs.
Total Weight of Aluminium and Iron in transformer: 79¼ lbs.
Regulation given approx. 3.5% at U.P. factor.

The coils will take up about 38 mms (1.5 inches) of the available 54 mms (2.13 inches) of window space.

With this value of x, the available variation in rating is 0.75 KVA to 4.25 KVA, achieved by varying the stack depth between 54 mms to 135 mms, and appropriate design of the coils. Flux density varies between 15,000 to 12,300 lines per square cm.

Example 5a—Conventional Transformer
Rating: 2.25 KVA (at 200 volts input and output)
Flux Density: 14,500 lines per square cm
Dimension x: 2.5 inches
Depth of Stack: 4.5 inches
Weight of Iron in Core: 47 lbs.
Diameter of Copper Wire: 0.120 inches (3 mms)

Primary Coil:

Turns	90
Turns/Layer	27
Layers	4

Secondary Coil:

Turns	92
Turns per layer	27
Layers	4

Total Length of Wire: 95 yards (86 metres)
Total Weight of Copper in Coils: 12.6 lbs.
Total Weight of Copper and Iron in the transformer: 59.6 lbs.
Resulting regulation approx. 2% at U.P. factor.

In this transformer, the coils will take up about 1.2 inches of the available 1.25 inches of window space.

With this value of x, the available variation in rating is 0.7 KVA to 2.25 KVA, achieved by varying the stack depth between 2.5 inches to 4.5 inches, and appropriate design of the coils. Flux density varies between 15,000 to 14,500 lines per square cm.

Example 5b—Transformer according to the Invention
Rating: 2.25 KVA (at 200 volts input and output)
Flux Density: 15,000 lines per square cm
Dimension x: 44 mms
Depth of Stack: 110 mms
Total Weight of Iron in core: 36.5 lbs.
Cross-sectional dimensions of Aluminium used for coils: 0.2 inches by 0.08 inches

Primary Coil:

Turns	130
Turns per layer	23
Layers	6

Secondary Coil:

Turns	136
Turns per layer	23
Layers	6

Total Length of Aluminium used: 127 yards or 115 metres
Total Weight of Aluminium in coils: 7.1 lbs.
Total Weight of Aluminium and Iron in transformer: 43.6 lbs.
Regulation given approx. 4% at U.P. factor

The coils will take up about 31.7 mms (1.25 inches) of the available 44 mms (1.73 inches) of window space.

With this value of x, the available variation in rating is from 0.35 KVA to 2.25 KVA, all at substantially the same flux density, achieved by varying the stack depth between 44 mms and 110 mms.

Example 6a—Conventional Transformer
Rating: 300 VA (at 200 volts input and output)
Flux Density: 15,000 lines per square cm
Dimension x: 1.5 inches
Depth of Stack: 2.25 inches
Weight of Iron in Core: 8½ lbs.
Diameter of Copper Wire: 0.40 inches

Primary Coil:

Turns	288
Turns/layer	48
Layers	6

Secondary Coil:

Turns	297
Turns per layer	48
Layers	7

Total Length of Wire: 171 yards (155 metres)
Total Weight of Copper in Coils: 2.5 lbs.
Total Weight of Copper and Iron in the transformer: 11 lbs.
Resulting regulation approx. 2.8% at U.P. factor

In this transformer, the coils will take up about .73 inches of the available 0.75 inches of window space.

With this value of x, the available variation in rating is from 130 VA to 300 VA, all at substantially the same flux density, achieved by varying the stack depth between 1.5 inches to 2.25 inches.

Example 6b—Transformer according to the Invention
Rating: 300 VA at 200 volts input and output
Flux Density: 15,000 lines per square cm
Dimension x: 28 mms
Depth of Stack: 70 mms
Total Weight of Iron in core: 9.25 lbs.
Diameter of Aluminium Wire used for coils: 0.052 inches (1.32 mms)

Primary Coil:

Turns	320
Turns per layer	56
Layers	6

Secondary Coil:

Turns	331
Turns per layer	56
Layers	6

Total Length of Wire used: 199 yards (180 metres)
Total Weight of Aluminium in coils: 1.47 lbs.
Total Weight of Aluminium and Iron in transformer: 10.72 lbs.

Regulation given approx. 3.3% at U.P. factor

The coils will take up about 21 mms (0.82 inches) of the available 28 mms (1.1 inches) of window space.

With this value of *x*, the available variation in rating is from 50 VA to 300 VA, all at substantially the same flux density, achieved by varynig the stack depth between 28 mms to 70 mms.

Example 7a—Conventional Transformer
Rating: 175 VA at 200 volts input and output
Flux Density: 15,000 lines per square cm
Dimension *x*: 1.25 inches
Depth of Stack: 2 inches
Weight of Iron in core: 5.2 lbs.
Diameter of Copper wire: 0.028 inches (0.710 mms)

Primary Coil:

Turns	393
Turns/Layer	55
Layers	8

Secondary Coil:

Turns	415
Turns per layer	55
Layers	8

Total Length of Wire: 201 yards (183 metres)
Total Weight of Copper in coils: 1.43 lbs.
Total Weight of Copper and Iron in the transformer: 6.63 lbs.
Resulting regulation approx. 3.8% at U.P. factor

In this transformer, the coils will take up about 0.6 inches of the available 0.625 inches of window space.

With this value of *x*, the available variation in rating is from 70 VA to 175 VA, all at substantially the same flux density, achieved by varying the stack depth between 1.25 inches to 2 inches.

Example 7b—Transformer according to the Invention
Rating: 175 VA at 200 Volts input and output
Flux Density: 15,000 lines per square cm
Dimension *x*: 23 mms
Depth of Stack: 57.5 mms
Total weight of Iron in core: 5.2 lbs.
Diameter of Aluminium wire used for coils: 0.034 inches (0.85 mms)

Primary Coil:

Turns	480
Turns per layer	70
Layers	7

Secondary Coil:

Turns	500
Turns per layer	70
Layers	7

Total Length of wire used: 250 yards (225 metres)
Total Weight of Aluminium in Coils: 0.786 lbs.
Total Weight of Aluminium and Iron in transformer: 6 lbs.
Regulation given approx. 5.8% at U.P. factor

The coils will take up about 17 mms (0.68 inches) of the available 23 mms (0.91 inches) of window space.

With this value of *x*, the available variation in rating is from 30 VA to 175 VA, all at substantially the same flux density, achieved by varying the stack depth between 23 mms to 57.5 mms.

Example 8a—Conventional Transformer
Rating: 95 VA (at 200 volts input and 200 volts output)
Flux Density: 15,000 lines per square cm
Dimension *x*: 1.0 inches
Depth of Stack: 1.75 inches
Weight of Iron in Core: 2.91 lbs.
Diameter of Copper Wire: 0.018 inches

Primary Coil:

Turns	556
Turns/Layer	59
Layers	10

Secondary Coil:

Turns	589
Turns per layer	59
Layers	10

Total Length of Wire: 238 yards (215 metres)
Total Weight of Copper in Coils: 0.71 lbs.
Total Weight of Copper and Iron in the transformer: 3.62 lbs.
Resulting regulation approx. 4.4% at U.P. factor

In this transformer, the coils will take up about 0.5 inches of the available 0.5 inches of window space.

With this value of *x*, the available variation in rating is from 30 VA to 95 VA, all at substantially the same flux density, achieved by varying the stack depth between 1 inch and 1.75 inches.

Example 8b—Transformer according to the Invention
Rating: 95 VA at 200 volts input and 200 volts output
Flux Density: 15,000 lines per square cm

Dimension x: 19 mms
Depth of Stack: 47.5 mms
Total Weight of Iron in core: 2.91 lbs.
Diameter of Aluminium wire used for coils: 0.021 inches (0.530 mms)

Primary Coil:

Turns	695
Turns per layer	89
Layers	8

Secondary Coil:

Turns	725
Turns per layer	89
Layers	9

Total Length of Wire used: 285 yards (258 metres)
Total Weight of Aluminium in coils. 0.342 lbs.
Total Weight of Aluminium and Iron in transformer: 3.252 lbs.
Regulation given approx: 5% at U.P. factor

The coils will take up about 13 mms (0.5 inches) of the available 19 mms (0.75 inches) of window space.

With this value of x, the available variation in rating is from 15 VA to 95 VA, all at substantially the same flux density, achieved by varying the stack depth between 19 mms to 47.5 mms.

Example 9a—Conventional Transformer
Rating: 15 VA (at 200 volts input and output)
Flux Density: 15,000 lines per square cm
Dimension x: 0.75 inches
Depth of Stack: 1 inch
Weight of Iron in Core: 0.94 lbs.
Diameter of Copper Wire: 0.0076 inches (0.19 mm)

Primary Coil:

Turns	1315
Turns/Layer	112
Layers	12

Secondary Coil:

Turns	1580
Turns per layer	112
Layers	14

Total Length of Wire: 395 yards (358 metres)
Total Weight of Copper in Coils: 0.207 lbs.
Total Weight of Copper and Iron in the transformer: 1.147 lbs.
Resulting regulation approx. 18.5% at U.P. factor

In this transformer, the coils will take up about 0.33 inches of the available .375 inches of window space.

With this value of x, the available variation in rating is from 8 VA to 15 VA, all at substantially the same flux density, achieved by varying the stack depth between 0.75 inches and 1 inch.

Example 9b—Transformer according to the Invention
Rating: 15 VA at 200 volts input and output
Flux Density: 15,000 lines per square cm
Dimension x: 14 mms
Depth of Stack: 35 mms
Total Weight of Iron in core: 1.16 lbs.
Diameter of Aluminium wire used for coils: 0.224 mms

Primary Coils:

Turns	1280
Turns per layer	140
Layers	10

Secondary Coil:

Turns	1450
Turns per layer	140
Layers	11

Total Length of wire used: 398 yards (360 metres)
Total Weight of Aluminium in coils: .085 lbs.
Total Weight of Aluminium and Iron in transformer: 1.245 lbs.
Regulation given about 13% at U.P. factor

The coils will take up about 8.4 mms (0.33 inches) of the available 14 mms (0.552 inches) of window space.

With this value of x, the available variation in rating is from 3 VA to 15 VA, all at substantially the same flux density, achieved by varying the stack depth between 14 mms and 35 mms.

It will be seen that, in each of Examples 1b to 8b, the maximum KVA available (within the specified limits of x to $2\frac{1}{2}x$ for stack depth) for each value of x is 6.25 times the minimum KVA, and it will be recognised that this range is considerably greater than that available in the conventional transformers of Examples 1a(i) and 2a to 8a. It should be understood that the conventional transformers described in Examples 1a to 8a with which transformers according to the invention have been compared, are typical commercially available transformers and thus it is considered that the advantages of the invention can be achieved in practical transformers.

It is considered that the specific values of x quoted above and defined as Size. Nos. 1 to 8 are the optimum. However, if an

alternative range of sizes is to be produced, it is nevertheless preferred that the ratios between the different values of x be preserved. For example, if in Size No. 1 of such an alternative range, the value of x is y mm, the preferred range of sizes would be:

Size No. 1	$x=y$ mms
Size No. 2	$x=19y/14$ mms
Size No. 3	$x=23y/14$ mms
Size No. 4	$x=28y/14$ mms
Size No. 5	$x=33y/14$ mms
Size No. 6	$x=44y/14$ mms
Size No. 7	$x=54y/14$ mms
Size No. 8	$x=64y/14$ mms

So far, the invention has been described in detail in connection with transformers. As previously indicated, the invention is, however, applicable to other electromagnetic devices.

Figure 8 is a diagram illustrating how the laminations of Figures 1 and 2 may be employed in a choke. The choke coil 100 is indicated diagrammatically as surrounding the limb of the core constituted by the centre limb 6 of the stack of laminations. This coil may be on a bobbin, but this is not shown in Figure 8. It may be desirable in chokes to have a relatively high magnetic reluctance in the magnetic circuit. In order to provide this, spacers 102, 104 and 106, of non-magnetic material, such as plastics, may be disposed between the I-members 16 and the associated respective E-shaped members 2 to provide gaps between the I-members and E-members.

It is preferred that the same range of sizes for the laminations, as defined by the dimension x, as used in the transformers as hereinbefore described in detail, also be used when the electromagnetic device is to be a choke. Similar advantages compared to the prior art chokes may be achieved in the chokes embodying the invention, and the additional window space available in constructions according to the invention is particularly advantageous in the case of chokes since the choke coil may require more room than transformer coils, and this is especially so in the case when the choke coil is made of aluminium. Thus, it will be understood that the coil 100 shown in Figure 8 is of aluminium wire.

In Figure 9, a saturable reactor embodying the invention is illustrated diagrammatically. As in the case of transformers, the magnetic reluctance in the magnetic circuit should be kept to a minimum and therefore the I-members 16 are shown in close contact with the E-members 2. AC coils 110 and 112 connected in series are shown wrapped around the limbs constituted by the limbs 4 and 8 of the E-members 2. The coils 110 and 112 are wound such that if magnetic flux induced by the coil 110 is flowing upwardly in the limb 8, then the flux produced at the same time by the coil 112 flows downwardly in the limb 4. A DC control winding 114 surrounds the limb of the core constituted by the centre limbs 6 of the stack of E-shaped members and is arranged in use such that flux produced thereby flows upwardly in the limb 6, as seen in Figure 9.

The employment of the invention in saturable reactors may provide the advantages hereinabove described specifically in connection with transformers, and is particularly advantageous since, even with aluminium wire as employed in the invention, there is adequate window space to accommodate the three coils 110, 112 and 114.

In the alternative form of saturable reactor shown in Figure 10, two separate magnetic cores 120 and 122 are provided. Each is made as described with reference to Figures 1 to 5. The two windings 110 and 112 of the saturable reactor are arranged on the limbs constituted by the centre limbs 6 of the E-shaped members of the respective different cores and are connected in series and wound so that while current is flowing in one clockwise as seen in Figure 10, current is flowing in the other anti-clockwise. The DC control winding is located around both the AC windings 110 and 112 and extends through the windows of the two cores.

In the case of saturable reactors, it is again preferred that the sizes of the laminations, as defined by the dimension x, should be as described with reference to transformers.

Various modifications are possible within the scope of the invention. For example, although the primary and secondary coils have been described as being one on top of the other as shown in Figures 4 and 5, they could be placed side by side. Also, conductors of other than circular cross-section may be used. In particular, the term "wire" as used in the following claims should be understood as including within its scope a conductor which is in the form of strip whose width is substantially less than the length and the width of the "windows" in the magnetic core, such that this narrow strip can be wound into coils having a plurality of turns, just as wire of circular cross-section can also be wound into coils having a plurality of turns.

It should be understood that although the dimensions of the various limbs of the laminations employed in the present invention have been given precisely in terms of x (for example $\frac{1}{2}x$) such values may vary within the practical limitations of manufacture. The references to such dimensions in the following claims should therefore be construed in this context.

WHAT I CLAIM IS:—

1. An E-shaped member for use as a lamination in the core of an electromagnetic device, in which, if the width of the centre of the three parallel limbs is x, the spacing between said centre limb and each of the outer limbs of said three is x, the width of each of said outer limbs and of the limb transverse thereto is $\frac{1}{2}x$, the length of said transverse limb is $4x$, the length of the centre limb and a first of said outer limbs is $3x$, and the length of the second outer limb is $3\frac{1}{2}x$ so that the free end portion thereof projects a distance $\frac{1}{2}x$ beyond the free ends of the centre and first outer limbs, the length of the three parallel limbs being measured from the inner edge of the transverse limb, and wherein x is within the range 14 mms to 64 mms.

2. An E-shaped member according to claim 1, wherein x equals 14 mms.

3. An E-shaped member according to claim 1, wherein x equals 19 mms.

4. An E-shaped member according to claim 1, wherein x equals 23 mms.

5. An E-shaped member according to claim 1, wherein x equals 28 mms.

6. An E-shaped member according to claim 1, wherein x equals 33 mms.

7. An E-shaped member according to claim 1, wherein x equals 44 mms.

8. An E-shaped member according to claim 1, wherein x equals 54 mms.

9. An E-shaped member according to claim 1, wherein x equals 64 mms.

10. An E-shaped member according to any one of the preceding claims in combination with an I-shaped member having a length of $3\frac{1}{2}x$ and a width of $\frac{1}{2}x$ and adapted to co-operate with the E-shaped member for forming a complete lamination in a magnetic core.

11. A method of making the combination of E-shaped and I-shaped members according to claim 10, wherein at least one pair of E-shaped members and at least one pair of I-shaped members are cut from a single sheet of material, wherein the lines of cut are substantially as illustrated in Figure 2 of the accompanying drawings.

12. A method of making a set comprising a plurality of laminations of different but related sizes comprising cutting E-shaped members, in each of which, if the width of the centre of the three parallel limbs is x, the spacing between said centre limb and each of the outer limbs of said three is x, the width of each of said outer limbs and of the limb transverse thereto is $\frac{1}{2}x$, the length of said transverse limb is $4x$, the length of the centre limb and a first of said outer limbs is $3x$, and the length of the second outer limb is $3\frac{1}{2}x$ so that the free end portion thereof projects a distance $\frac{1}{2}x$ beyond the free ends of the centre and first outer limbs, the length of the three parallel limbs being measured from the inner edge of the transverse limb, and cutting I-shaped members from sheet material; each I-shaped member having a length of $3\frac{1}{2}x$ and a width of $\frac{1}{2}x$; wherein the different sizes of the plurality of laminations are related such that if, in a first size of lamination, the dimension x is equal to y units, then the dimension x in other sizes of lamination are as follows: $19y/14$; $23y/14$; $28y/14$; $33y/14$; $44y/14$; $54y/14$; and $64y/14$ units.

13. A method as claimed in claim 12 wherein at least one pair of E-shaped members and at least one pair of I-shaped members of each size of lamination are cut from a single sheet of material.

14. A method according to claim 12 or claim 13 in which y equals 14 mms.

15. Laminations of different sizes when produced by the method of claim 12 or claim 13 or claim 14.

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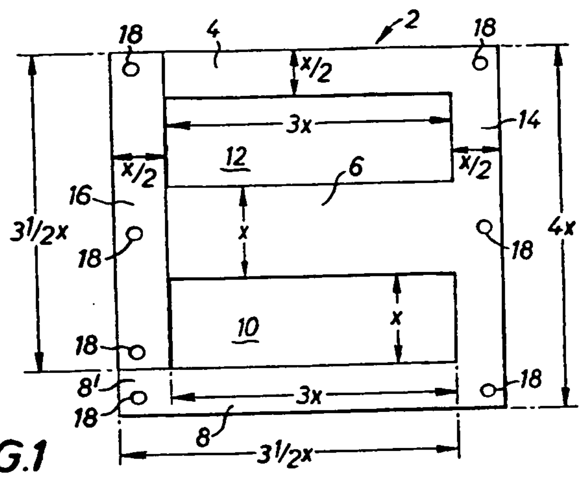

18
4
2
18
x/2
3x
14
x/2
12
6
x/2
16
3 1/2 x
x
4x
18
18
10
x
18
18
8'
3x
18
18
8
3 1/2 x

FIG.1

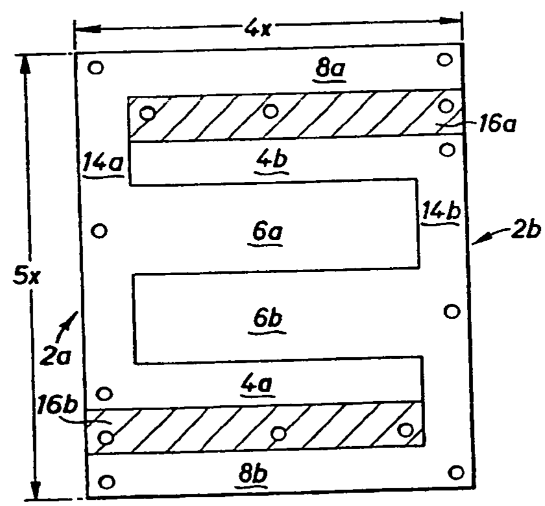

4x
8a
16a
14a
4b
14b
6a
2b
5x
6b
2a
4a
16b
8b

FIG.2

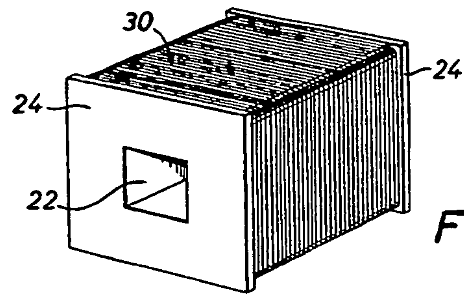


FIG.3

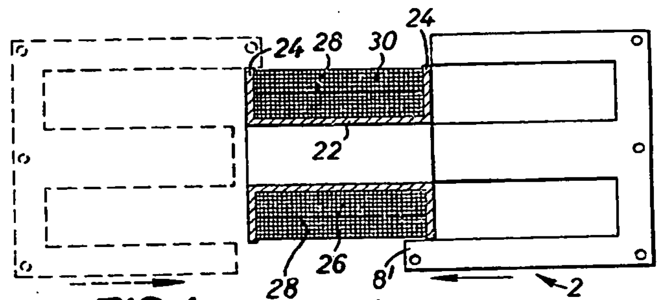


FIG.4

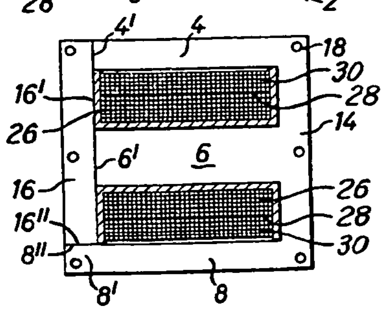


FIG.5

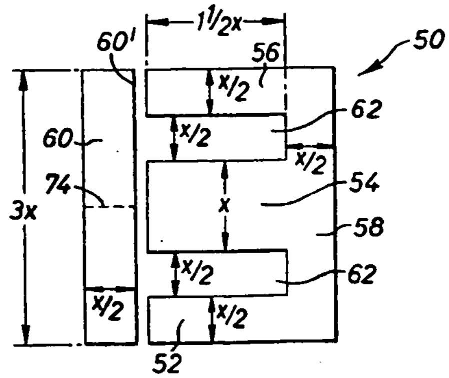

1½x
60'
56
50
x/2
62
60
x/2
x/2
54
74
3x
x
58
x/2
62
x/2
x/2
52

FIG.6

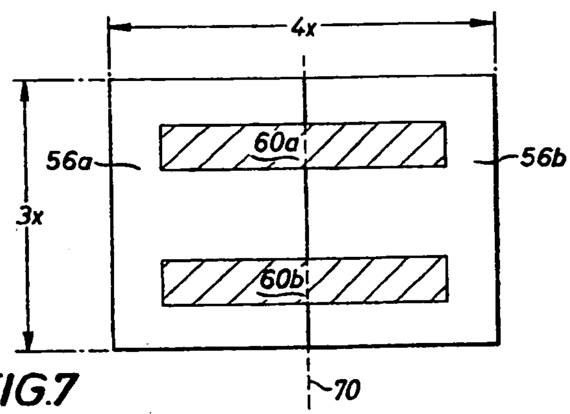

4x
60a
56a
56b
3x
60b
70

FIG.7

FIG.8

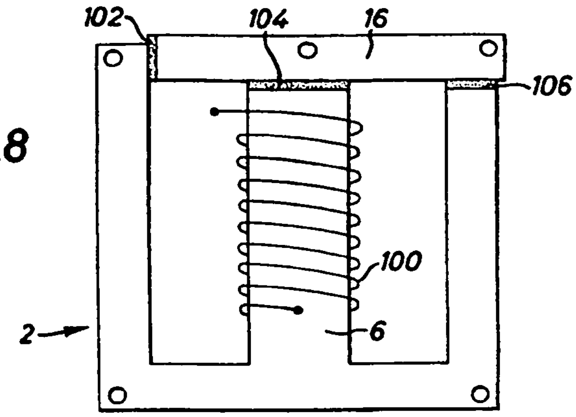
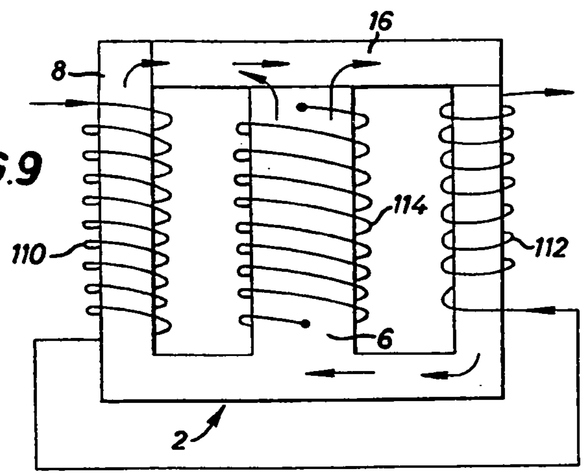


FIG.9



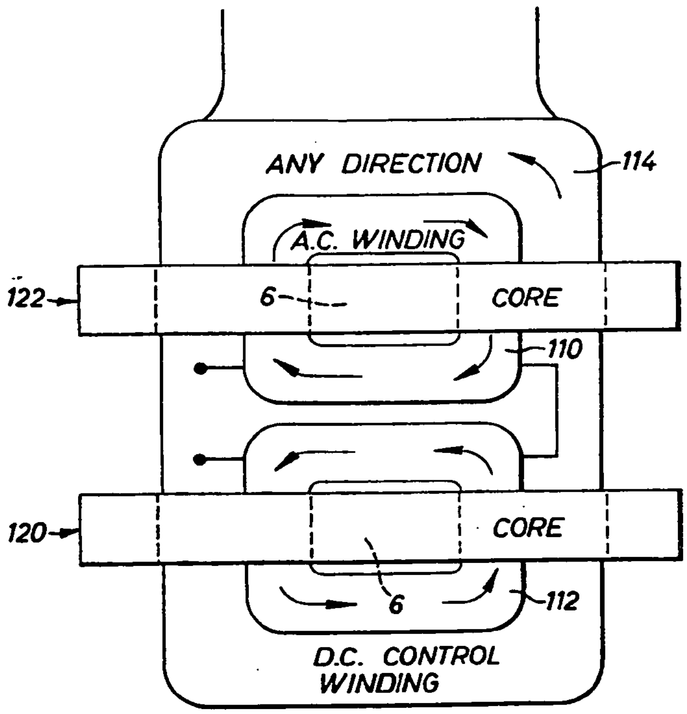

ANY DIRECTION
114
A.C. WINDING
122
6
CORE
110
120
CORE
6
112
D.C. CONTROL WINDING

FIG.10